

## FERTILIZER MICRODOSING TECHNOLOGY IN SORGHUM, MILLET AND MAIZE PRODUCTION AT SMALL-SCALE LEVEL IN AFRICA: A REVIEW

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### ABSTRACT

World population is alarmingly increasing, to feed the growing population, farmers must increase food production. Mineral fertilizer application takes the lion-share on crop productivity. However, due to the high cost of fertilizer, majority of African farmers add smaller than the recommended rate. Therefore, the farmers must adopt a technology that is environmentally friendly and minimizes dose of fertilizer keeping productivity higher than conventional fertilization. Microdosing (small and affordable quantities) fertilizer application produces higher grain yield as compared to control and banding application. Application of 0.3g NPK to 6g of NPK per pocket could increase yield of millet in range of 31.3% to 90.3 %. Similarly, application of 0.3 g NPK to 4 g NPK per pocket could increase yield of sorghum 40.9 % to 83 %. Microdosing fertilizer application is feasible and profitable than conventional fertilizer application. However, fertilizers in Africa are found in 50 kg package, which are not affordable by the poor resource farmers. The availability of fertilizer in affordable package is very crucial in expanding the technology. Moreover, the farmers must have the opportunity to inventory credit like warrantage system so that they borrow money to use it for input cost and store the crops after harvest when the price of the crops are low and resell them when the prices are higher. The use of the microdosing method brings entire changes to the existing fertilizer application methods; hence, there is a need for a strong linkage among researchers, farmers, and policy makers.

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## INTRODUCTION

Agriculture is the dominant economic activity mainly by smallholder farmers who have two hectares or less comprise 80% of the farms in Africa (Delaney et al., 2011). African farmers have been unable to move out of poverty because of the failure to increase agriculture productivity. It is caused by lack of adoption and application of modern agricultural inputs such as chemical fertilizer, improved seeds, pesticides and irrigation.

Soils in Africa are inherently less fertile as compared in Asia where the Green Revolution took place (Voortman et al., 2000). In Africa, the low inherent fertility (Giller et al. 2006; Tittonell et al. 2005; Zingore et al. 2007) is exacerbated by low, poorly distributed rainfall and high temperatures. Inorganic fertilizers have been responsible for an increased agricultural productivity. However, the cost of fertilizers in Africa are unaffordable by the small-scale poor farmers. The cost of inorganic fertilizers is increasing enormously, to the extent that they are out of reach for resource poor farmers. The high cost of inorganic fertilizer and the risk (the low and erratic rainfall and unfavorable market condition) are the major constraining factors for fertilizer use in Africa. Hence, farmers are not willing to apply fertilizer at all or they add smaller than recommended rates which result in low in yield.

In Africa, mainly in semi-arid areas, the farmers grow maize (*Zea Mays* L.), sorghum (*Sorghum Bicolor* (L.) Moench) and pearl millet (*Pennisetum Glaucum* (L.) R.Br.) as the major cereal grain. Application of small amounts of mineral fertilizer in the planting hole has been practiced in some West Africa. The technology has found to be a more efficient way to apply mineral fertilizer as compared to broadcasting. This technique increases yields at a low cost (Aune *et al*, 2007, Aune and Bationo 2008). This method would give a great opportunity for small-scale farmers to produce cereals at low production cost and that minimize risks associated to production failure due to unfavorable climatic conditions. Moreover, this technology would reduce the loss of nutrients through leaching because this technique also increases nutrient use efficiency. Therefore, the technology has a huge contribution in protecting environmental pollution. The current global scenario firmly emphasizes the need to adopt eco-friendly agricultural practices for sustainable food production. Although the technology has such merits, still it is limited only in certain Africa countries. Therefore, the **objective** of this review paper is *to summarize and show the opportunities and constraints in utilizing the microdosing fertilizer application technology*.

## FERTILIZATION AND LIMING

World population is alarmingly increasing, to feed a growing population, farmers must increase food production. Increased use of inorganic fertilizers has been responsible for an important share of world-wide agricultural productivity growth (Kelly, 2015). However, some farmers do not apply the recommended rate of fertilizer. The reason could be lack of knowledge about fertility status of their farm and cost of fertilizers.

Soil pH is one of the factor that determine availability of nutrients. Low pH or high pH of soils have detrimental effect on availability of some nutrients. In acidic soils, for instance, because phosphates and some micronutrients bind strongly to clay particles and are therefore unavailable to crops. Excessive application of fertilizers, to meet the crop

nutrient requirements, may cause wastage and environmental pollution. Liming must be taken priority than addition of more fertilizers. Liming adjust the pH neutral and increase the availability of nutrients thereby reduce fertilization.

Root growth of crops are limited in acidic soils. Roots of plants grown in acidic soils are consistently shorter than when they grow in neutral soils (Caires *et al.*, 2008). Increase in surface area of roots of crops have significant effect on uptake of water and nutrients. Liming of acidic soils neutralize and improve roots of crops. Application of lime in acidic soil improved water use efficiency in maize, due to an enhanced root surface area and hence, enhanced water uptake (de Barros *et al.*, 2007).

High cost of fertilizer and the requirement of high amount of lime (6 tons' lime per hectare) (Kormawa et al., 2003) is challenge to poor farmers. To reduce the quantities to an affordable and small, adoption of relevant technology is unquestionable. The International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) developed a precision fertilization technique called fertilizer 'microdosing'. Microdose technology is the application of small mineral fertilizer doses in the seed hole (pocket) during sowing or next to the seedling after emergence (10 days after sowing) (Figure 1 and 2). The technology makes use of small quantities of fertilizers (reduce environmental pollution) and increase yield of cereal crops and make agriculture more sustainable.

**Figure – 1:** *Planting Pockets (Holes)* (Source: ECHO, 2013)



**Figure – 2:** *Millet Growing in Planting Pockets in Burkina Faso* (Source: ECHO, 2013)



## EFFECT OF MICRODOSING ON GRAIN AND FODDER YIELD

Application of fertilizer microdosing produces higher grain yield as compared to control and banding fertilizer application (table 1). In these specific countries yield increased in range of 31.3% to 90.3 % in millet using 10 kg ha<sup>-1</sup> to 60 kg ha<sup>-1</sup>NPK fertilizer, and 40.9 % to 167 % in sorghum using 7.5kg ha<sup>-1</sup> to 37.5 kg ha<sup>-1</sup> NPK fertilizer. Application of 0.3g NPK per pocket to 6 g NPK per pocket were used in the study areas of different African countries (table 1). This indicates that microdose application of fertilizer is more efficient in increasing yield of cereals than conventional fertilization. Adding fertilizer close to the seed in soil could contributed in increase fertilizer uptake by crops. There is a threshold or limit to the dose of fertilizer application in planting pocket microdose techniques. High level fertilization has negative effect on seed germination and plant stand count. That could be due the burning effect of fertilizer.

**Table – 1:** Rate of Microdose NPK Fertilization and their Respective Yield Increase in Millet and Sorghum Crops at different African Countries

Fertilizer (NPK)		Country	Crop	Yield Increase		Source
g/pocket	Kg /ha			Kg/ha	%	
0.3g NPK	5kg NPK	Mali	Millet	122	55.7	Aune et al. 2007
4g NPK	80kg NPK	Mali	Millet	491	79.4	Tabo et al., 2006
6 g NPK	60kg NPK	Niger	Millet	394	90.3	Hayashi et al., 2008
0.3g NPK	10Kg NPK	Sudan	Millet	104	31.3	Aune & Ousman 2011
0.3g NPK	7.5kg NPK	Mali	Sorghum	281	40.9	Aune et al., 2007
0.6g NPK	25kg NPK	Sudan	Sorghum	282	68.7	Aune & Ousman 2011
4g NPK	125kg NPK	Burkina Faso	Sorghum	317	63.1	Tabo et al., 2006
4g NPK	120kg NPK	Mali	Sorghum	567	83.0	Tabo et al., 2006
0.9g NPK	37.5kg NPK	Sudan	Sorghum	859	167	Abdalla et al., 2015

Different fertilizers can be applied to increase productivity of crops. The most frequent fertilizers used in conventional fertilization in Africa are NPK, DAP and DAP + urea. Although the type of fertilizer to be applied depends on the type of soil and quality of the soil, multi-year results indicated that application DAP + Urea increased yields by 91% compared to the control and by 10% with respect to DAP and NPK treatments (Tabo et al., 2006). Application of DAP alone or along with urea showed increase in yield compared to conventional fertilizer application and control. Millet increased in yield from 28.7% to 107.5% using DAP fertilizer at rate of 20 kg DAP ha<sup>-1</sup> (table 2) in Niger. Although similar rate of fertilizer (20 kg DAP ha<sup>-1</sup>) was applied, yield variations were recorded that could be due to spatial variability in rain, variation in length of growing seasons, (Sime and Aune, 2014) agroecological variation and soil quality variation. The response of crops to fertilization depends on the soil quality, yield decrease with increasing soil quality (Giller et al., 2006).

**Table – 2:** Rate of Microdose DAP Fertilization and their Respective Yield Increase in Millet, Sorghum and Maize Crops at Different African Countries

Fertilizer (DAP)		Country	Crop	Yield increase		Source
g/pocket	Kg /ha			Kg/ha	%	
2g DAP	20kg DAP	Niger	Millet	230	61.4	Tabo et al., 2006
2g DAP	20kg DAP	Niger	Millet	69	28.7	Biielders & Gerard, 2015
2g DAP	20kg DAP	Niger	Millet	329	40.0	Ibrahim et al., 2015a
2g DAP	20kg DAP	Niger	Millet	548	107.5	Ibrahim et al., 2015b
0.3g DAP	7.5kg DAP	Mali	Sorghum	281	40.9	Aune et al., 2007
0.5gDAP & Urea	27kg DAP & 27 kg Urea	Ethiopia	Maize	1205	19	Sime & Aune, 2014
0.5gDAP & Urea	27kg DAP & 27 kg Urea	Ethiopia	Maize	1810	45	Sime & Aune, 2014
0.5gDAP & Urea	27kg DAP & 27 kg Urea	Ethiopia	Maize	1671	46	Sime & Aune, 2014

Farmers apart from grain yield, they need the biomass yield to use it as fire wood, construction material and animal feed. Microdosing increase not only the grain yield of crops but also increase the biological biomass of the crops. Tabo et al (2006) reported that microdosing increase fodder yield as compared to control and conventional fertilization. This would have its own contribution to farmers practicing crop-livestock farming.

## EFFECT OF MICRODOSING ON STRIGA SPP

Cereal crop productivity in African is low due to lack access to improved cultivars, fertilizers, and attack of the crops by pest and parasitic weed such as *Striga Spp*. *Striga* reproduce from seeds (Csurhes *et al.*, 2013). Seeds remain viable in soil for long years. Seeds only germinate in close proximity to the roots of a suitable host. These species attack the major cereal crops (such as sorghum and maize) in Africa. From 70 to 100% of crop yield loss was recorded due to *Striga* infestation (Frederick *et al.*, 2011). Musselman *et al.* (2001) reported that *Striga* spp are causing annual crop losses estimated at US\$7 billion annually.

*Striga* attack has a direct relation with the nutritional status of the soil (Jamil *et al.*, 2011a). Infertile soils have resulted to high infestation of *Striga*. It implies that *Striga* is known as an indicator of low soil fertility. To minimize the negative effect of *Striga* attack in cereals, mineral nutrients should be applied in soil (Yonli *et al.*, 2011). Research findings (Kim *et al.*, 1997; Pageau *et al.*, 2003) showed that fertilizer has direct or indirect effect on *Striga* infection. In other words, improving the fertility status of the farm by fertilizer application would have positive effect in suppressing weed infestation. Esilaba (2006) reported that 64% reduction in *S. hermonthica* emergence in maize using 39 kg N ha<sup>-1</sup> as calcium ammonium nitrate. However, availability of fertilizer to African farmers is low due to poverty. Therefore, a technology that tackle such challenge must be adopted. Microdosing, low doses of fertilizer application in small holes close to the host plant, is a promising strategy to lower the destructive effect of *Striga* on cereal (Jamil *et al.*, 2014).

Decreasing strigolactone secretion and *Striga* infection were recorded in sorghum with increasing microdosing of DAP fertilizer (Jamil *et al.*, 2013).

## PROFITABILITY OF MICRODOSING

Profitability is an essential condition for adoption of technologies. To make the economic analysis, a value-cost ratio (VCR) is used. A VCR is a mathematical method to evaluate the effectiveness of micro dosing. The VCR for fertilizer treatment measures the increase in revenue relative to the increased cost of fertilizer compared to the control treatment. Although a VCR of 2 set as the minimum ratio needed to minimize financial risk of resource poor farmers, a VCR above 4 is required in order to have an acceptable level of risk in dryland areas (Koning *et al.*, 1998).

Climate change poses real challenge to African agriculture. Most African countries farmers' livelihoods depend on rainfed agriculture. Erratic rainfall distribution and low in amount of rainfall decrease the productivity of crops. This is because soil moisture ensures the availability of nutrients and uptake by plants readily. Rainfall variability and increase in temperature is therefore a threat to the economy African countries and livelihoods of millions of the poor African farmers.

The unfavorable market condition is another challenge that farmers face. The low cost of farmers' products in the market discourage them. Therefore, to minimize the low rainfall and unfavorable market risks the profitability of the farmers must exceed so that it covers the risks. Crop productivity can be increased at a low cost and very moderate risk to farmers. Application of small quantities fertilizer with microdosing become more profitable and minimizes risk than application of large quantities of fertilizer.

## CHALLENGES AND OPPORTUNITIES IN MICRODOSING

Microdosing requires a lot of labor and is time consuming (Tabo *et al.*, 2006; Twomlow *et al.*, 2010). To apply microdosing fertilizer application, farmers must prepare a number of small holes depending on the farm size, intra and inter-row spacing of each crop. The labor demand in microdosing is nearly twice that is needed to banding fertilizer application (Sime and Aune, 2014). However, in majority of African countries availability of labor is high and labor cost is low. Therefore, microdosing is feasible and profitable than banding techniques in Africa.

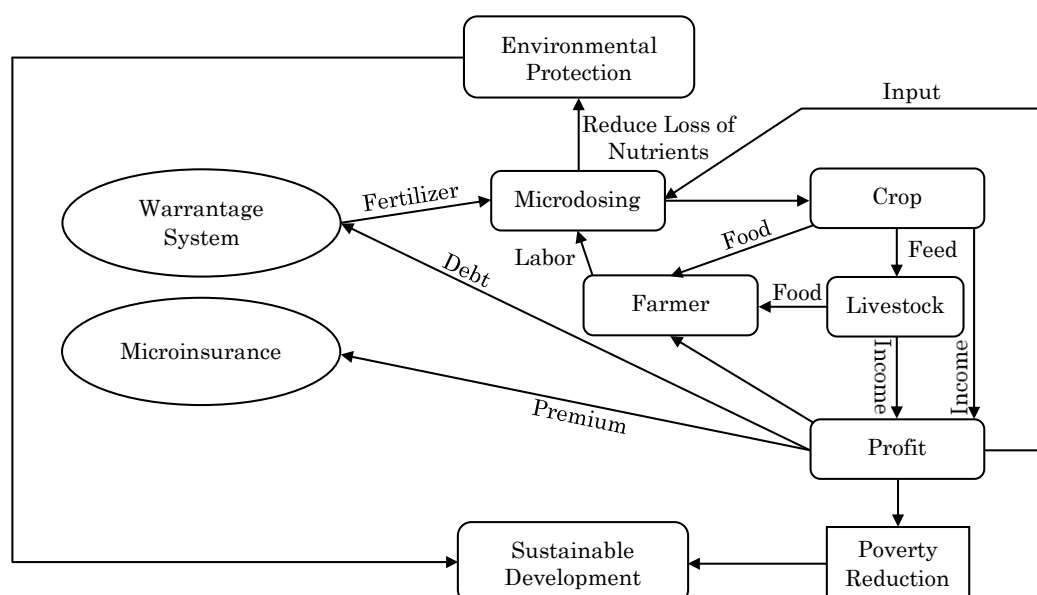
Fertilizer is costly for poor African farmers, they cannot afford to buy the recommended quantities of fertilizer required for their crops, so they apply reduced levels or none at all. The poor farmers wait applying the fertilizer until they are able to afford the fertilizer during the growing season. Delayed application of the fertilizer has showed no reduction in millet yield in microdosing fertilization (Hayashi *et al.*, 2008). It indicates that microdosing technique provides opportunities to the farmers to apply fertilizers within 10 to 60 days after sowing (Hayashi *et al.*, 2008).

In Africa, grain costs are relatively low and fertilizer cost are relatively high. The cause for high cost of fertilizer could be transportation and distribution cost which are significant component of the total cost of fertilizer (Bumb *et al.*, 2011). Fertilizers in Africa are found in 50kg package, which are not affordable by the poor resource farmers. The

availability of the fertilizer at the right time and in affordable package is very crucial in expanding the technology.

The frequency of the prevalence of drought is increasing which has negative impact on productivity of crops. The existence of social safety nets and functioning financial markets ensure that farmers are either insured against losses, can borrow around them, or can receive help from the government to maintain livelihoods during bad times. Being most African countries lead rainfed agriculture, they start sowing when the farmers run out of money. They must survive and therefore they buy food than fertilizers. On contrary, in next year to have food they must produce crops. Thus, there must be a system that enable them continue growing without food shortage. Hence, the farmers must have insurance and involve in warrantage system.

**Chart – 1:** *The Integrated Approach of Microdosing Fertilizer Application and Finance System to Ensure Sustainable Development*



Lack of insurance or warrantage system make the farmers reluctance to purchase fertilizer. The low-income households can manage their risks through microinsurance. Microinsurance can assist them to maintain a sense of financial confidence even in the face of significant vulnerability. Micro-insurance can be developed and delivered by insurance companies, mutual funds, MFIs, NGOs, and governments or semi-public bodies (Demessie, 2016). However, it is only the insurance companies and deposit-taking MFIs which are allowed, by law, to issue microinsurance policies in Ethiopia (Demessie, 2016). Policies should be amended in such a way that cooperatives become insurers.

ICRISAT introduced warrantage system to solve the financial problem related to the farmers' incapability to afford fertilizers, and to use them in microdosing. The system allows farmers to store crops, using them as inventory credit at a time when crop cost is low, typically right after harvest, and then to resell the safely stored crops when the prices are high (ICRISAT, 2009). The system enables the poor farmers to buy fertilizers. This system, together with the accessibility of fertilizer in small or affordable package (example: 5kg, 10kg bag), can contribute in solving the challenges farmers would face in adopting of the technology.

Although the fertilizer microdosing is promoted in semi-arid areas in Africa but widely adopted in west Africa. The technology believed to have a tremendous contribution in economy, environmental protection and even would be taken as climate adaptation mechanism. The finance system (warrantage and microinsurance) must be integrated with application microdosing technology to ensure sustainable development in Africa (Chart 1).

In general, microdosing is simple and low-cost technology for increasing yields. The use of the microdosing method brings entire changes to the existing fertilizer application methods, there is a need for a strong linkage among researchers, farmers, and policy makers. The knowledge transfer would be more productive if it becomes part of the respective national agricultural extension system (Sime and Aune, 2014). Some major constraints to the widespread adoption of microdosing technology include access to fertilizer; access to credit; insufficient flows of information and trainings to farmers; and inappropriate policies (ICRISAT, 2009). Agricultural extension is one of the main policy instruments used to accelerate the dissemination of knowledge and skills and promote the adoption of modern technologies among farmers.

## CONCLUSIONS

Microdose technology is the application of small mineral fertilizer doses in the seed hole (pocket) during sowing or next to the seedling after emergence (10 days after sowing). Microdosing technology has a number of advantages. It makes nutrient uptake easier, reduce nutrient leaching, increase nutrient use efficiency, improves plant growth, increase yield, minimize production cost, increase income of small-scale farmers. The technology would have its own contribution on increasing the number of farmers to participate due to low production cost and low risks related to erratic rainfall distribution and low rainfall amount in semi-arid areas. To ensure sustainable development, microdosing technology should be supported by finance system (warrantage system and microinsurance). Therefore, countries should focus on key policy areas that emphasize availability of inorganic fertilizer in affordable package, and access to credit and microinsurance. To ensure food security and reduce poverty in small holder African farmers, microdosing fertilizer application technology should be adopted.

## REFERENCES

- [1] Abdalla, E. A., Osman, A.K., Maki, M.A., Nur, F.M., Ali, S.B., & Aune, J. B., (2015). The Response of Sorghum, Groundnut, Sesame, and Cowpea to Seed Priming and Fertilizer Micro-Dosing in South Kordofan State, Sudan *Agronomy*, 5, 476-490.
- [2] Aune, J. B., & Bationo, A., (2008). Agricultural intensification in the Sahel - the ladder approach. *Agricultural Systems* 98(2):119–125.
- [3] Aune, J. B., Doumbia, M. & Berthe, A. (2007) Microfertilizing sorghum and pearl millet in Mali: Agronomic, economic and social feasibility. *Outlook on Agriculture* 36, 199–203.
- [4] Aune, J. B., & Ousman, A. (2011) Effect of seed priming and micro-dosing of fertilizer on sorghum and pearl millet in Western Sudan. *Experimental Agriculture* 47, 419–430.

- 
- [5] Biielders C.I., & Gerard B. (2015) Millet response to microdosing fertilization in south-wester Niger. Effect of antecedent fertility management and environmental factors. *Field Crops Research* 171:165-175.
  - [6] Bumb, B. L., Johnson, J. E., & Fuentes, P. A. (2011). Policy Options for Improving Regional Fertilizer Markets in West Africa. (IFPRI Discussion Paper No. 01084). IFPRI.
  - [7] Caires, E.F., Garbuio, F.J., Churka, S., Barth, G., & Corrêa, J.C.L. (2008). Effects of soil acidity amelioration by surface liming on no-till corn, soybean, and wheat root growth and yield. *European Journal Agronomy* 28, 57–64.
  - [8] Csurhes, S., Markula, A., & Zhou, Y. (2013). Weed risk assessment: Witch weeds (*Striga spp.*). Dicko, M.H., Gruppen, H., Traore, A.S., Voragen, A.G.J. and Van Berkel., W.J.H. 2006."Review: Sorghum grain as human food in Africa: relevance of starch content and amylase activities. *African Journal of Biotechnology*, 5: 384-395.
  - [9] de Barros, I., Gaiser, T., Lange, F. M., & Römheld, V. (2007). Mineral nutrition and water use patterns of a maize/cowpea intercrop on a highly acidic soil of the tropic semiarid. *Field Crops Research* 101, 26–36.
  - [10] Delaney, S., Livingston, G., & Schonberger, S. (2011). Sub-Saharan Africa: The state of smallholders in agriculture. Paper presented at the IFAD Conference on New Directions for Smallholder Agriculture. January 24-25. Rome: IFAD.
  - [11] Demessie, M. (2016). An Assessment of willingness to pay for Microinsurance Service by Low-income Households in Ethiopia–Special Reference with Adamitulu Rural Community, Oromia Region, Ethiopia (Unpublished MSc Thesis), Hawassa University [Demessie, 2016].
  - [12] ECHO (2013). Zai pit system. Technical Note #78
  - [13] Esilaba, A.O. (2006). Options for *Striga* management in Kenya. Kenya Agricultural Research Institute (KARI) Technical Note.
  - [14] Frederick, C., & Niguse, T. (2011). Nitrogen in combination with *Desmodium intortum* Sons, New York. pp .108-127. Effectively Suppresses *Striga asiatica* in a sorghum-*Desmodium* intercropping system. *Journal of Agriculture and Rural Development in the Tropics and Sub-tropic*, 112 (1): 19-28.
  - [15] Giller, K.E., Rowe, E.C., de Ridder, N., & van Keulen, H. (2006). Resource use dynamics and interactions in the tropics: Scaling up in space and time. *Agricultural Systems* 88, 8–27.
  - [16] Hayashi, K., Abdoulaye, T., Gerard, B., & Bationo, A. (2008) Evaluation of application timing in fertilizer micro-dosing technology on millet production in Niger, West Africa. *Nutrient Cycling in Agroecosystems* 80, 257–265.
  - [17] Ibrahim, A., Abaidoo, R.C., Fatondji, D., & Opoku, A. (2015a): Integrated use of fertilizer micro-dosing and *Acacia tumida* mulching increases millet yield and water use efficiency in Sahelian semi-arid environment. *Nutrient Cycling in Agroecosystems* 103:375-388.
  - [18] Ibrahim, A., Pasternak, D., & Fatondji, D. (2015b) Impact of depth of placement of mineral fertilizer micro-dosing on growth, yield and partial nutrient balance in pearl millet cropping system in the Sahel. *The Journal of Agricultural Science Cambridge* 153:1412-1421.
-

- [19] ICRISAT (2009). Fertilizer Microdosing: Boosting Production in Unproductive Lands ICRISAT.
- [20] Jamil, M., Charnikhova, T., Jamil, T., Ali, Z., Mohamed, N.E.M.A., Mourik T.V., & Bouwmeester, H. J. (2014). Influence of fertilizer microdosing on strigolactone production and *Striga hermonthica* parasitism in pearl millet. *International Journal of Agriculture & Biology* 16: 935-940
- [21] Jamil, M., T. Charnikhova, C., Cardoso, T., Jamil, K., Ueno, F., Verstappen, T.A., & Bouwmeester, H. J. (2011a). Quantification of the relationship between strigolactones and *Striga hermonthica* infection in rice under varying levels of nitrogen and phosphorus. *Weed Research* 51: 373–385
- [22] Jamil, M., T., Van Mourik, A., Charnikhova, T., & Bouwmeester, H. J. (2013) Effect of di-ammonium phosphate application on strigolactones production and *Striga hermonthica* infection in three sorghum cultivars. *Weed Research* 53: 121–130
- [23] Kelly, V. (2005) Farmer's Demand for Fertilizer in Sub-Saharan Africa. In International Department of Agricultural Economics Michigan State University East Lansing, MI 48824-1039, USA
- [24] Kim, S.K., Adetimirin, V.O., & Akintunde, A.Y. (1997) Nitrogen effects on *Striga hermonthica* infestation, grain yield, and agronomic traits of tolerant and susceptible maize hybrids. *Crop Science* 37:711–716
- [25] Koning, N., Heerink, N., Kauffman, S., (1998) Integrated Soil Improvement and Agricultural Development in West Africa: Why Current Policy Approaches Fail; Wageningen Agricultural University: Wageningen, the Netherlands.
- [26] Kormawa, P., Munyemana, A., & Soule, B. (2003) Fertilizer market reforms and factors influencing fertilizer use by small-scale farmers in Benin. *Agriculture, Ecosystems and Environment* 100, 129-136.
- [27] Musselman, L.J., Yoder, J.I., & Westwood, J.H. (2001) Parasitic plants major problem of food crops, *Science*, 293: 1434.
- [28] Pageau, K., Simier, P., Le Bizec, B., Robins, R.J., & Fer, A. (2003) Characterization of nitrogen relationships between *Pearl millet bicolor* and the root hemiparasitic angiosperm *Striga hermonthica* (Del.) Benth. using (KNO<sub>3</sub>)–N<sub>15</sub> as isotopic tracer. *Journal of Experimental Biology* 54:789–799
- [29] Sime, G., & Aune, J. B. (2014) Maize response to fertilizer dosing at three sites in the Central Rift Valley of Ethiopia. *Agronomy* 4:436–451.
- [30] Tabo, R., Bationo, A. D., Maimouna, K., Hassane, O., & Koala, S. (2006). Fertilizer microdosing for the prosperity of small-scale farmers in the Sahel: Final report. (Global Theme on Agroecosystems Report No. 23). Niamey, Niger: International Crops Research Institute for the Semi-Arid Tropics.
- [31] Tittonell, P., Vanlauwe, B., Leffelaar, P.A., Shepherd, K.D., & Giller, K.E. (2005) Exploring diversity in soil fertility management of smallholder farmers in western Kenya. II. Within farm variability in resource allocation, nutrient flows and soil fertility status. *Agric, Ecosystems and Environment* 110: 166–184
- [32] Twomlow, S., Rohrbach, D., Dimes, J., Rusike, J., Mupangwa, W., Ncube, B., Hove, L., Moyo, M., Mashingaidze, N., & Mahposha, P. (2010). Micro-dosing as a pathway to

- Africa's Green Revolution: Evidence from broad-scale on-farm trials. *Nutrient Cycling in Agroecosystems*, 88(1), 3-15. doi:[10.1007/s10705-008-9200-4](https://doi.org/10.1007/s10705-008-9200-4)
- [33] Voortman, R., Sonneveld, B., & Keyzer, M. (2000) African Land Ecology: Opportunities and Constraints for Development. Center for International Development Working Paper No. 37. Boston: Harvard University.
- [34] Yonli, D., Traore, H., van Mourik, T. A., Hess, D. E., Sereme, P., & Sankara, P. (2011) Integrated control of *Striga hermonthica* (Del.) Benth. in Burkina Faso through host plant resistance, biocontrol and fertilizers. *International Journal of Biology and Chemical Sciences* 5: 3734–3741
- [35] Zingore, S., Murwira, H. K., Delve, R. J., Giller, K. E. (2007). Influence of nutrient management strategies on variability of soil fertility, crop yields and nutrient balances on smallholder farms in Zimbabwe. *Agriculture, Ecosystems & Environment* 119, 112–126.